THE WORLD-RECORD 42-MINUTE HOLT, MISSOURI, RAINSTORM

GEORGE A. LOTT

Division of Hydrologic Services, U. S. Weather Bureau,* Washington, D. C.

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INTRODUCTION

The Holt, Mo., storm of June 22, 1947, is the outstanding example of a very intense, small-area rainstorm. The point-rainfall value of 12 inches in 42 minutes is a world record [1]. Figure 1 includes an isohyetal map showing the results of a Corps of Engineers bucket survey conducted shortly after the storm. The totals represent rainfall during the afternoon and/or evening of the 22d only. Figure 2 shows the average depth of storm rainfall over areas up to 4,000 square miles in the Holt center during the storm period.

This report will concern itself mainly with presenting the meteorological data available in this most unusual storm and suggesting a possible rain-producing mechanism.

June 1947 was the wettest June of record (1888–1947) in northern Missouri. The Holt storm itself caused major local floods which, in turn, added to the already swollen Missouri River. A disastrous flood at St. Louis on July 2, exceeded up to that time only by the flood of 1844, was the result of this June rainfall.

The Holt storm occurred as a local intensification in a long, narrow, warm sector convective system (the leading edge of which may be interpreted as an instability line) a short distance ahead of a surface cold front. This elongated convective system deposited rainfall totals of ½ to 2½ inches in eastern Kansas and Nebraska before the intensification took place. The heavy burst of rain in the Holt storm lasted about 45 minutes at a given point, but light showers continued until after the cold front passage several hours later.

SURFACE SYNOPTIC SITUATION

Figure 3 illustrates the large-scale synoptic conditions about 6 hours before the Holt storm. The extensive air mass in the eastern part of the country was unusually cold for the season. The front separating the eastern cold air mass from the warm air over southwestern Missouri was diffuse. The tropical air in the warm sector had a very high moisture content; e. g., the surface dewpoint of 76° F. at Little Rock, Ark., is exceeded only about 1½ percent of the hours in an average June [2].

Figures 4 and 5 are detailed weather maps of the region of greatest interest. They were selected from a series of

*In cooperation with the Corps of Engineers, Department of the Army.

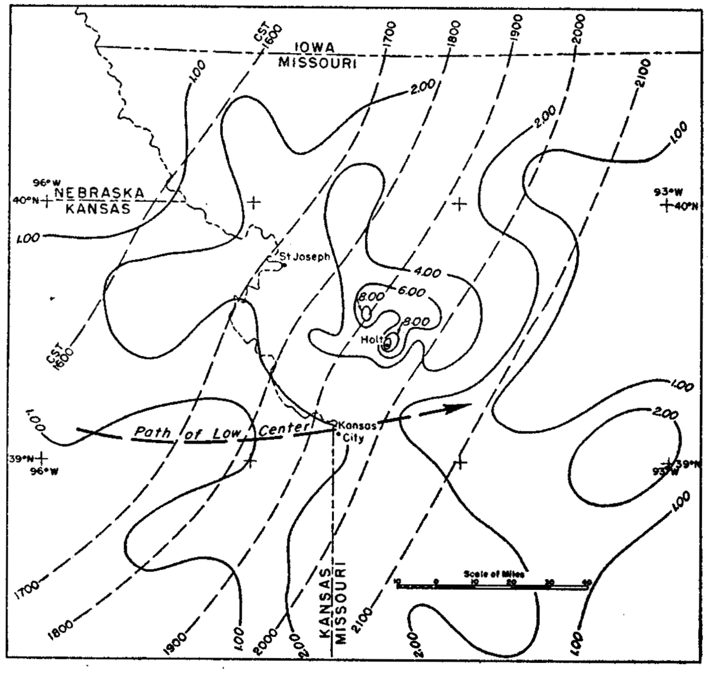

FIGURE 1.—Isohyetal map of storm rainfall in Holt, Mo. region, June 22, 1947. Precipitation amounts are in inches. Isochrones show hourly positions of the forward edge of the convective system.

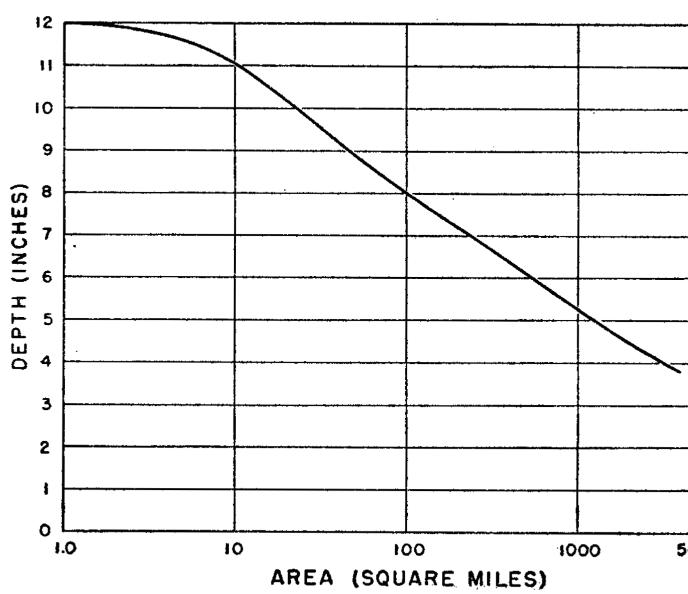

FIGURE 2.—Average amount of storm rainfall June 22, 1947 over areas up to 4000 square miles.

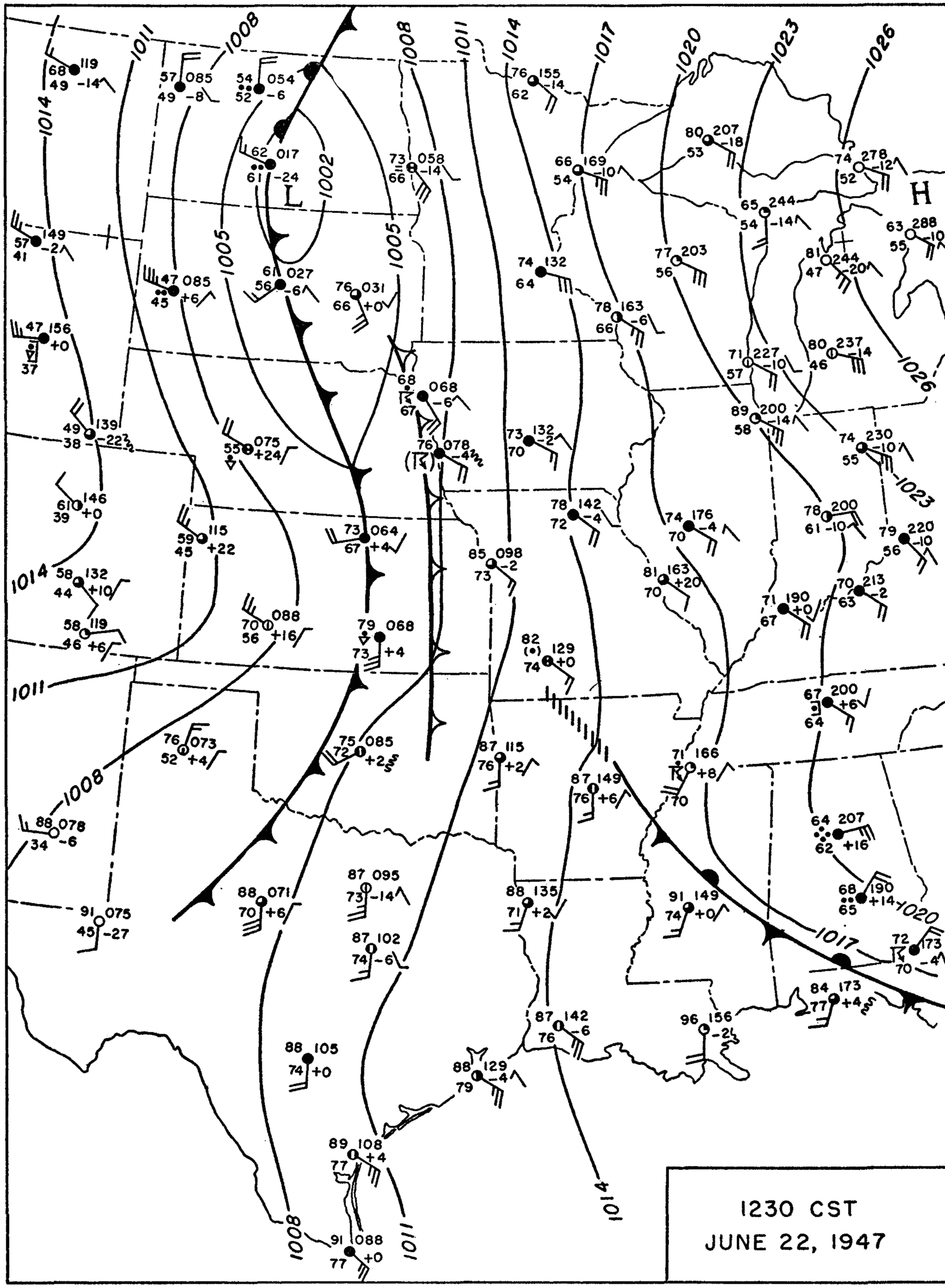

FIGURE 3.—Surface chart for 1230 CST, June 22, 1947 about 6 hours before the Holt storm. Note the high dewpoints in the warm sector. (After WBAN Analysis Center.)

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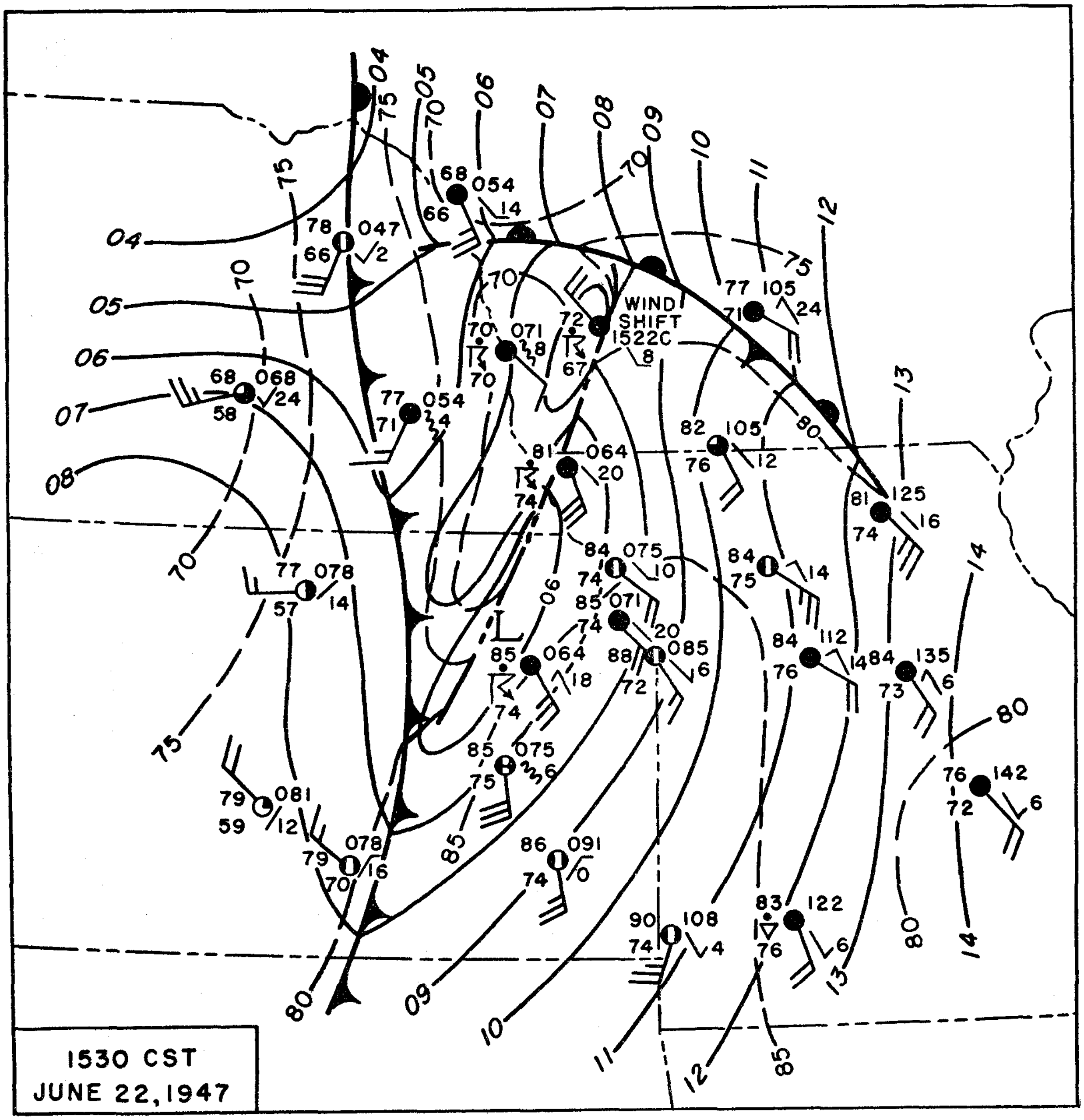

FIGURE 4.—Surface chart for 1530 CST June 22, 1947. Note closed central isobar. Compare with figures 3 and 5.

hourly charts drawn for the period from 1530 to 2130 CST, June 22. The data for the series came from the hourly airway sequences and, in a few cases, directly from the original autographic records. To aid in the delineation of weak systems, isobars are drawn for every millibar and isotherms for each 5° F.

On figure 4 the area of convective showers is clearly evident approaching the northwestern corner of Missouri. A noteworthy feature of the surface chart is the closed Low along the southern border of the convective system. At 1630 CST this Low was centered near Topeka, Kans., and had a central pressure of about 1,005.5 mb. On succeeding hourly charts the Low was tracked in an eastward direction and is seen near Kansas City on the 1830 CST map (fig. 5). The track of the Low center is plotted on figure 1. Apparently little change in intensity occurred until about 1900 CST, after which gradual filling took place. By 2130 CST no trace of this surface Low could be found.

It is interesting to speculate about the reason for formation of this closed low center. For the most part, the Low seemed to come into being as a result of rising pressures to the northwest within the trough itself. The pressure rise in the trough was associated with rain-cooled air of the thunderstorms in the convective system. At the same time the pressure remained steady over Iowa and north-central Missouri because of blocking of the

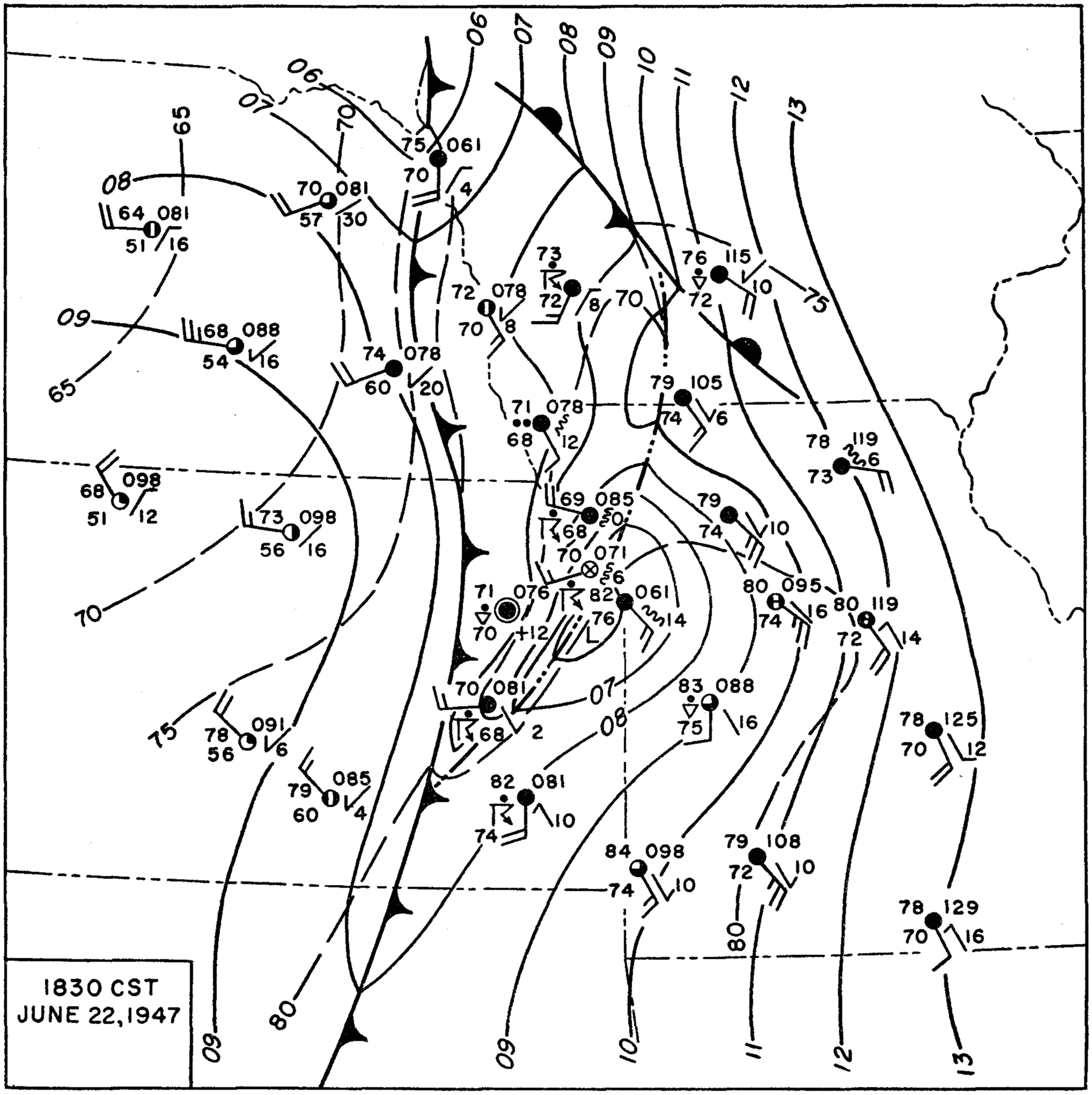

FIGURE 5.—Surface chart for 1830 CST, June 22, 1947. Compare with figures 3 and 4.

large High over the northeast (fig. 3). The effect was to leave a small system of low pressure cut off from the parent trough in the warm sector.

Figure 1 also shows hourly positions of the forward edge of the convective system. The positions were determined by the beginning of heavy rain which coincided very closely with the wind-shift line. Records from the Weather Bureau First-Order Airport Stations and about 50 Cooperative Observers in the area were available for analysis. The position of the rainfall center, relative to the surface Low, is of interest. A reference to figure 1 shows that the rainfall was relatively light along and south of the track of the Low. North of the path the rainfall increased rapidly to about latitude 39°30′ N. and then declined. In an west-east direction the most intense rainfall fell at about 94°20′ W. Although the central pressure of the Low did not vary much between 1600 and 1900 CST, the rainfall rate to the north of it increased constantly with time. An element that seems to have been associated with the intensity of rainfall was the pressure gradient north of the Low. The following table gives the gradient as measured from the Low center along the line of the eastern edge of the convective system.

Map time (CST)	1730	1830	1930	2030
Gradient (mb./mi.)	.025	.040	.038	.020

By 2130 the gradient was very weak and the rainfall had become light. The Holt storm occurred about midway between 40° N. and the surface Low center, where the gradient was the most intense. It can be seen, furthermore that between the hours of 1800 and 2000 CST the gradient was strong and relatively constant. From figure 1 it is evident that it was during this time period that the storm flourished.

This small Low then seems to have been of great importance in the Holt storm. The upper air structure above the Low was, therefore, studied in great detail and is presented in a later section.

RAOB ANALYSIS

The 1500 GMT raob taken at Oklahoma City (fig. 6) is the most representative sounding in the warm air which subsequently supplied the moisture for the Holt storm. The sounding points up a rather common picture of conditions in tropical air on days with violent convective phenomena. A very moist layer about 5,000 feet thick gave way to much drier conditions above, with a stable transition layer between. The pseudo-wet-bulb curve (plotted on fig. 6) shows that convective instability existed in the column up to the 660-mb. level, notwithstanding the stable layer. Thus, if this column were lifted until the air became saturated, it would have a lapse rate greater than moist adiabatic. The level of free convection for surface air was located at about 700 mb. Consequently, according to the parcel method, the air would be stable for small perturbations but unstable for large upward impulses.

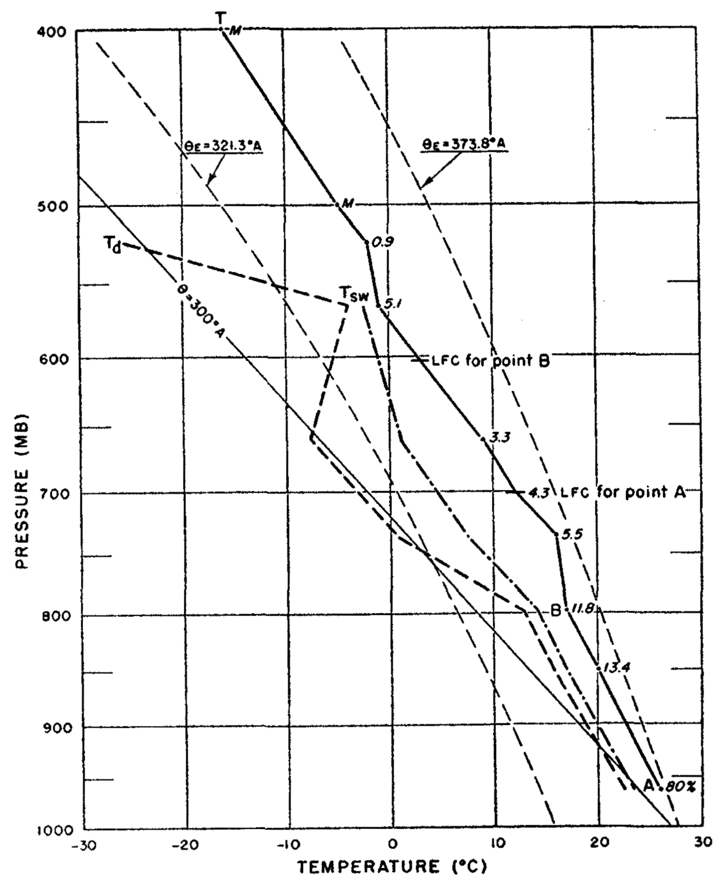

FIGURE 6.—Upper air sounding in the warm air, Oklahoma City, 1500 GMT, June 22, 1947, about 10 hours previous to the Holt storm. LFC stands for level of free convection.

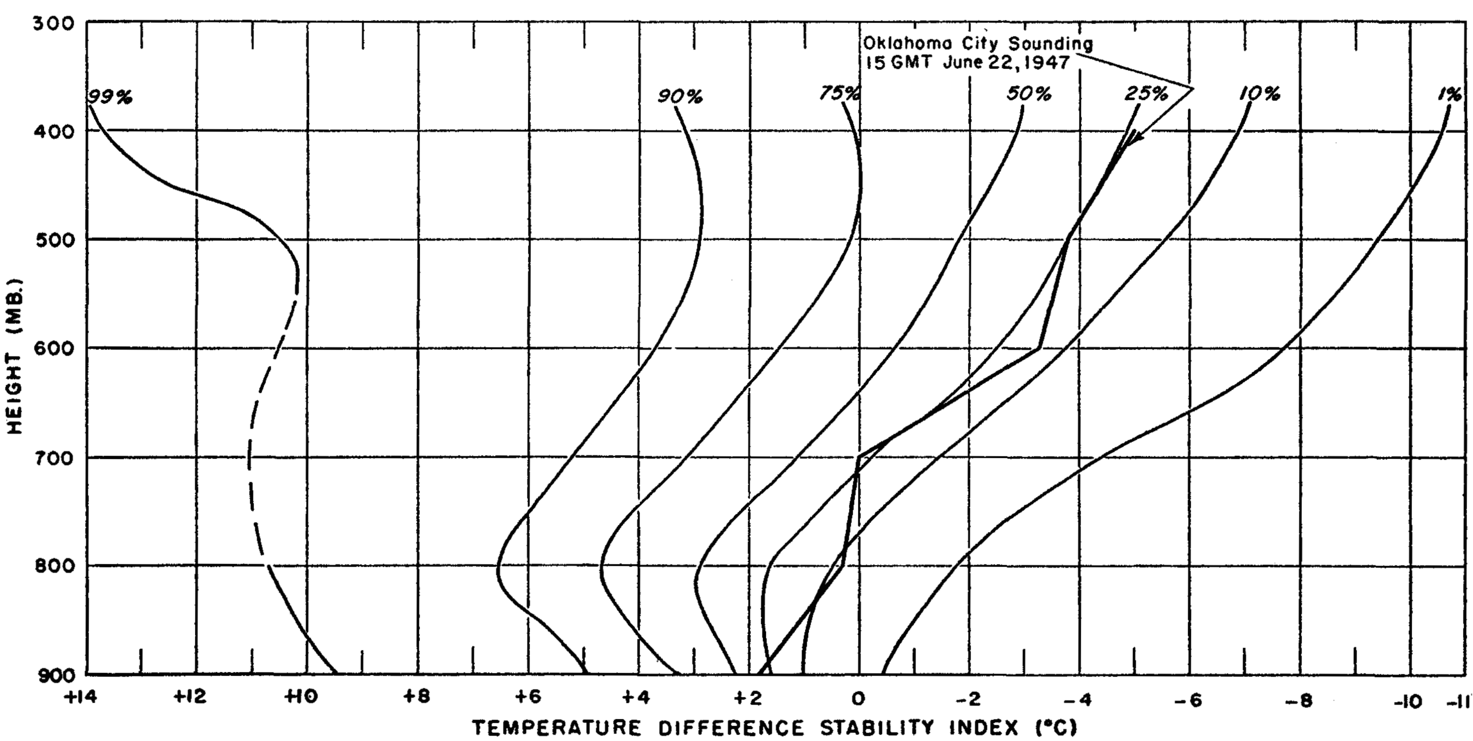

FIGURE 7.—Diagram comparing conditional instability of the Oklahoma City 1500 GMT sounding (heavy line) with average instability as measured by temperature difference computed from 282 Oklahoma City summer soundings. Light lines represent percent of time atmosphere is more unstable than the indicated temperature difference.

In order to gain some idea of the relative frequency of conditional instability of the magnitude found in the Holt storm as measured by the Oklahoma City sounding, a series of 282 Oklahoma City summer soundings were analyzed in the following manner. The temperature difference between the lifted 950-mb. parcel and the observed temperatures at 900, 800, 700, 600, 500 and 400 mb. were tabulated. In figure 7 the light lines represent the percent of time that the atmosphere is more unstable than the indicated temperature difference. The heavy line shows the 1500 GMT June 22, 1947, Oklahoma City sounding. It appears that the 950-mb. parcel (about 700 feet above the ground) when lifted to 800 mb., was the most unstable relative to the usual atmospheric stability. It must be borne in mind that some change in the lapse rate undoubtedly occurred between Oklahoma City and Holt, Mo.

UPPER AIR SYNOPTIC SITUATION

Figures 8 and 9 are the 850- and 700-mb. charts for 0300 GMT June 23, 1947. These maps show observed conditions 3 hours after the Holt storm and after the surface Low had disappeared. In order to assess the effect of the surface Low and to get some idea of the upper air structure at the time of the storm, the following procedure was used to construct synthetic constant-level charts. First, the constant-level charts (1,000, 850, 700,

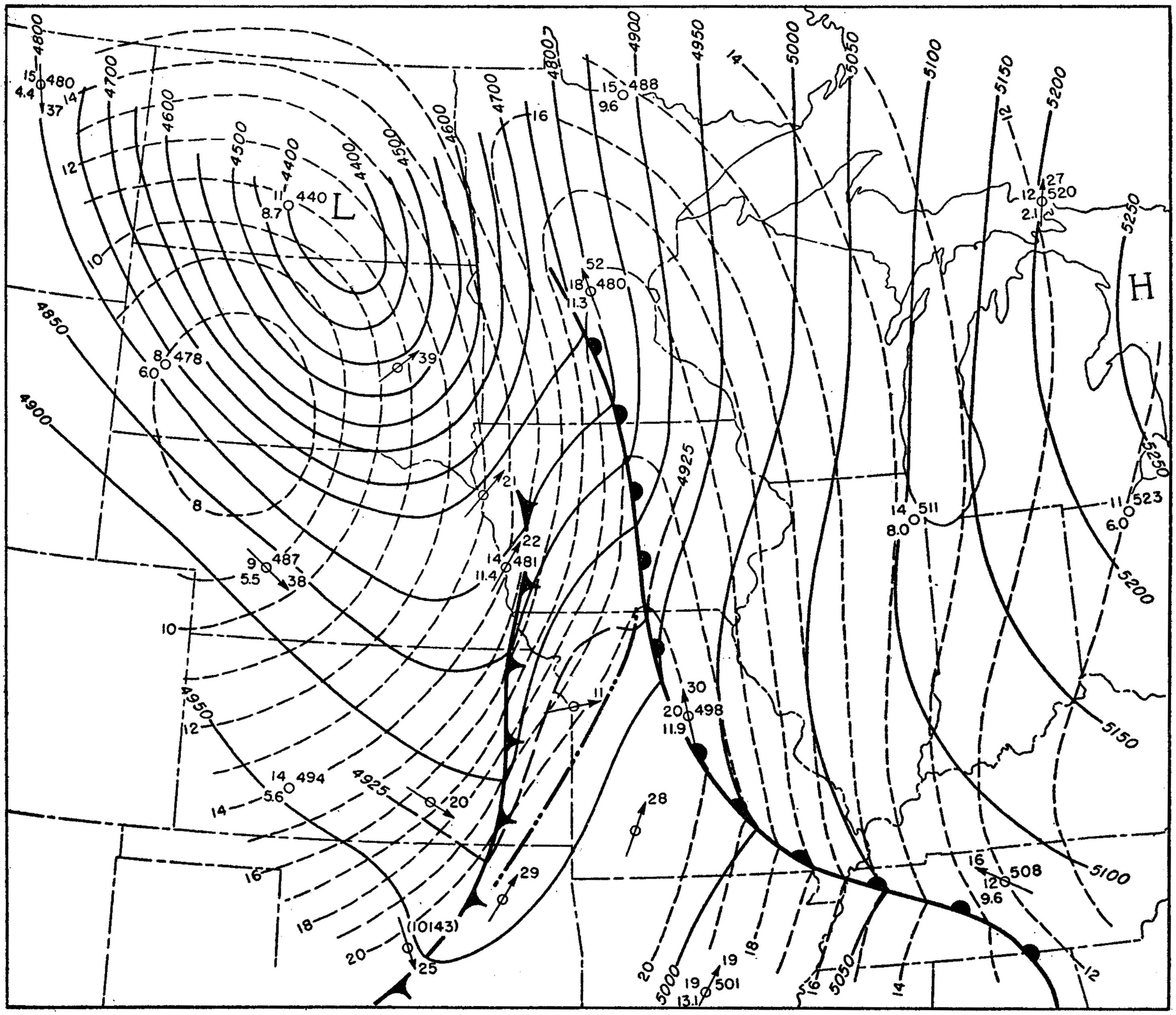

FIGURE 8.—850-mb. chart for 0300 GMT, June 23, 1947, three hours after the Holt storm. Contours are in feet (solid lines), isotherms in °C. (dashed lines).

500, and 300 mb.), for 1500 GMT of the 22d and 0300 GMT of the 23d were carefully analyzed, using small intervals of temperature and height. Thickness charts were then constructed for the 1,000–850, 850–700, 700–500, and 500–300-mb. layers for both 1500 GMT and 0300 GMT. Since the 1900 CST isochrone (see fig. 1) approximately bisects the Holt storm area, this time was chosen to illustrate the flow aloft at the time of the great storm. Thickness lines were then interpolated between the map times for 1900 CST. For the most part, objective linear interpolation of thickness lines was possible, but in some sections judgment was necessary, especially in local areas where a confused change in pattern was evident.

Figures 10–13 show the resultant 850-, 700-, 500-, and 300-mb. charts. In each case 50-ft. contours are used, and the thickness lines (proportional to the mean virtual temperature of the respective column) are also included. The edge of the convection area for 1900 CST and the total storm isohyetal pattern appear in each of these figures (the shaded portion of the isohyetal pattern is the area of intense rain, i. e., greater than about 6 in./hr. at map time).

A glance at the maps shows that the surface Low was reflected in the flow aloft up to at least the 500-mb. level, although the closed circulation seems to have been confined to the 850-mb. level only.

At the 850-mb. level (fig. 10) the Low was still very marked. An inflow from the east almost at right angles

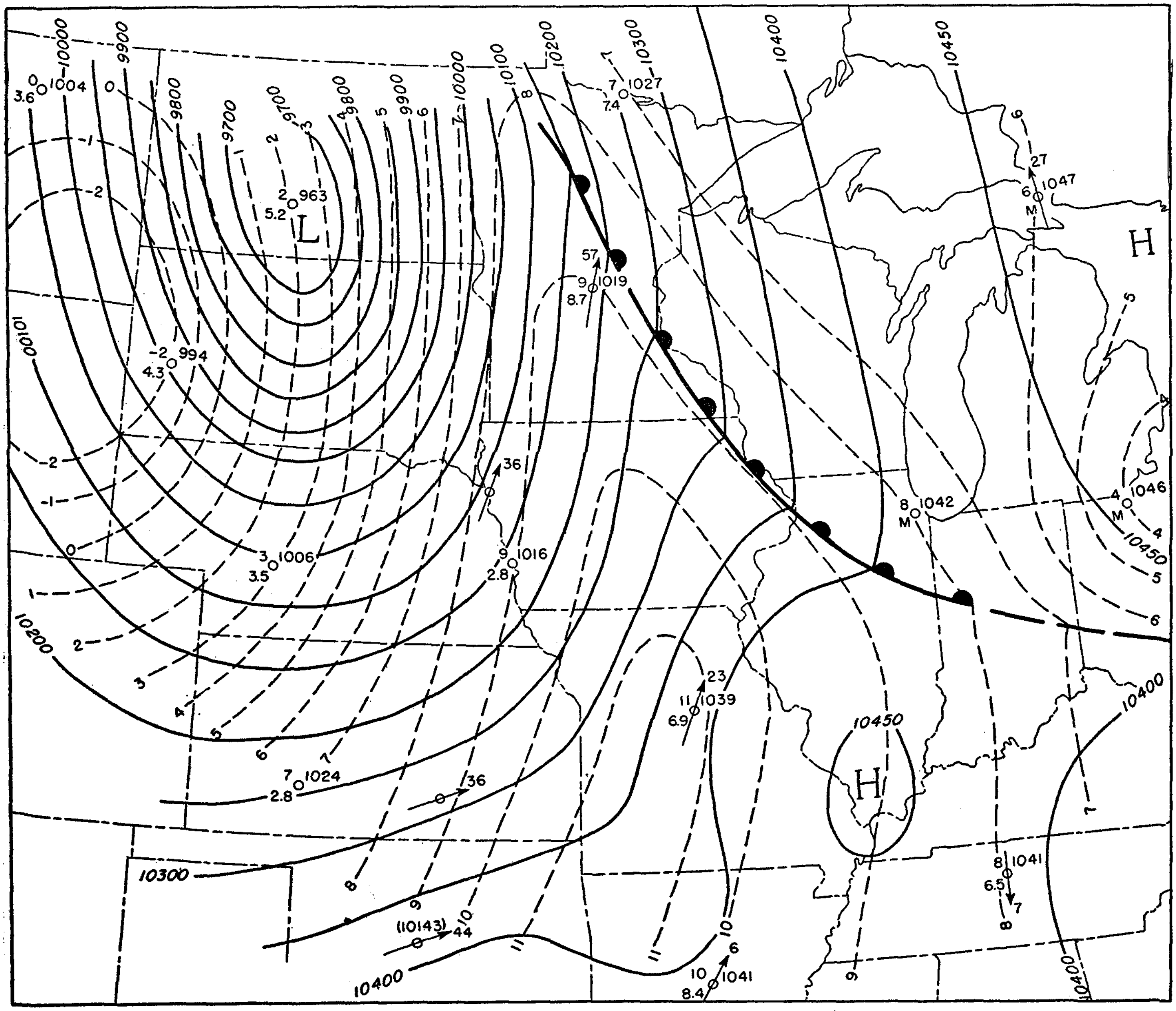

FIGURE 9.—700-mb. chart for 0300 GMT, June 23, 1947, three hours after the Holt storm. Contours are in feet (solid lines), isotherms in °C. (dashed lines).

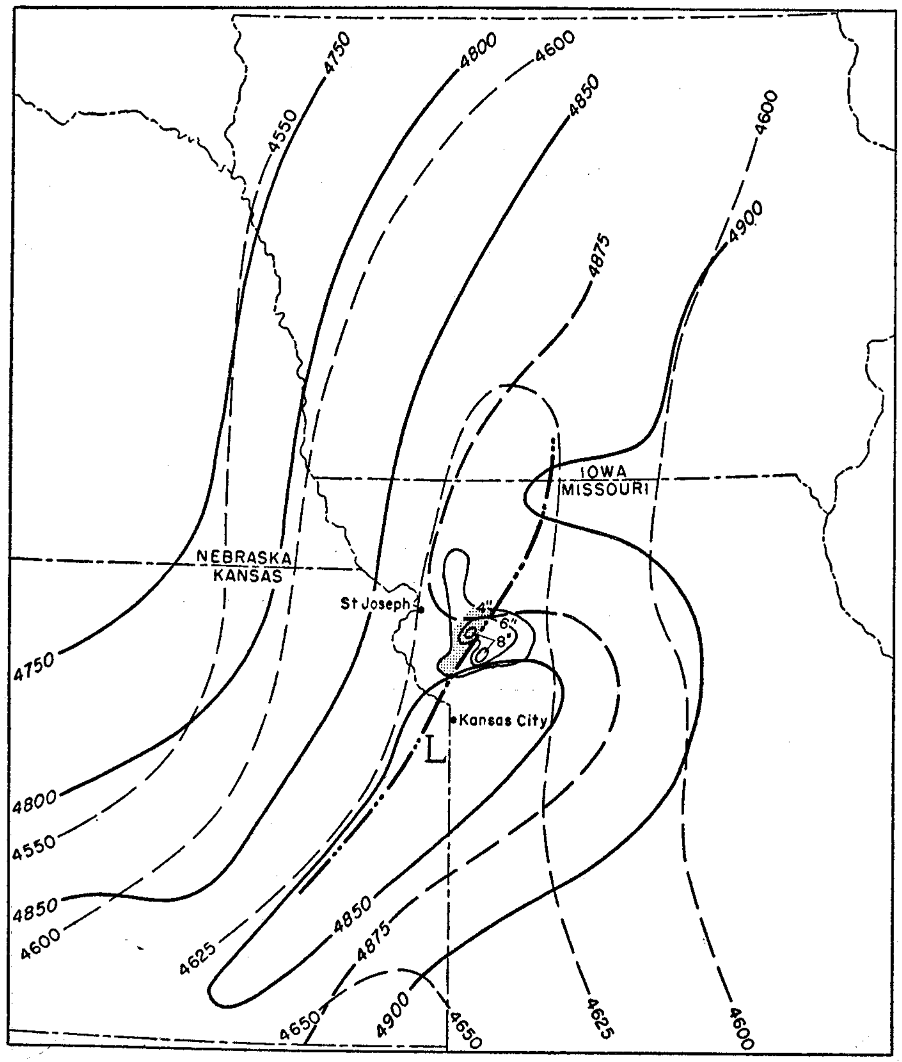

FIGURE 10.—850-mb. chart constructed as described in text for 1900 CST, June 22, 1947, the time of the Holt storm. Heavy lines are pressure contours (ft.); thin dashed lines are thickness contours (ft.) of 1000–850-mb. layer. Heavy dash-dot line represents leading edge of convection area at surface. Shaded portion of superimposed isohyetal pattern indicates rainfall rate of greater than 6 in./hr. at map time.

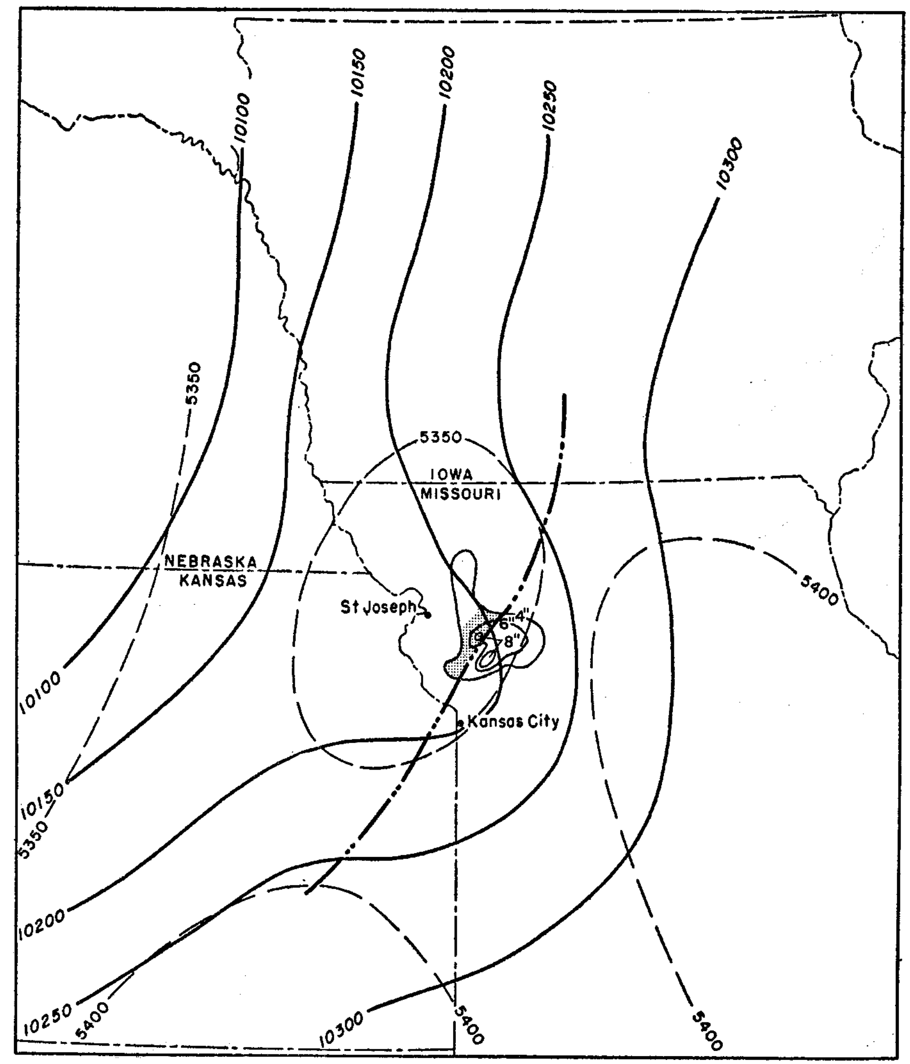

FIGURE 11.—700-mb. chart constructed as described in text for 1900 CST, June 22, 1947, the time of the Holt storm. Heavy lines are pressure contours (ft.); thin dashed lines are thickness contours (ft.) of 850–700-mb. layer. Heavy dash-dot line represents leading edge of convection area at surface. Shaded portion of superimposed isohyetal pattern indicates rainfall rate of greater than 6 in./hr. at map time.

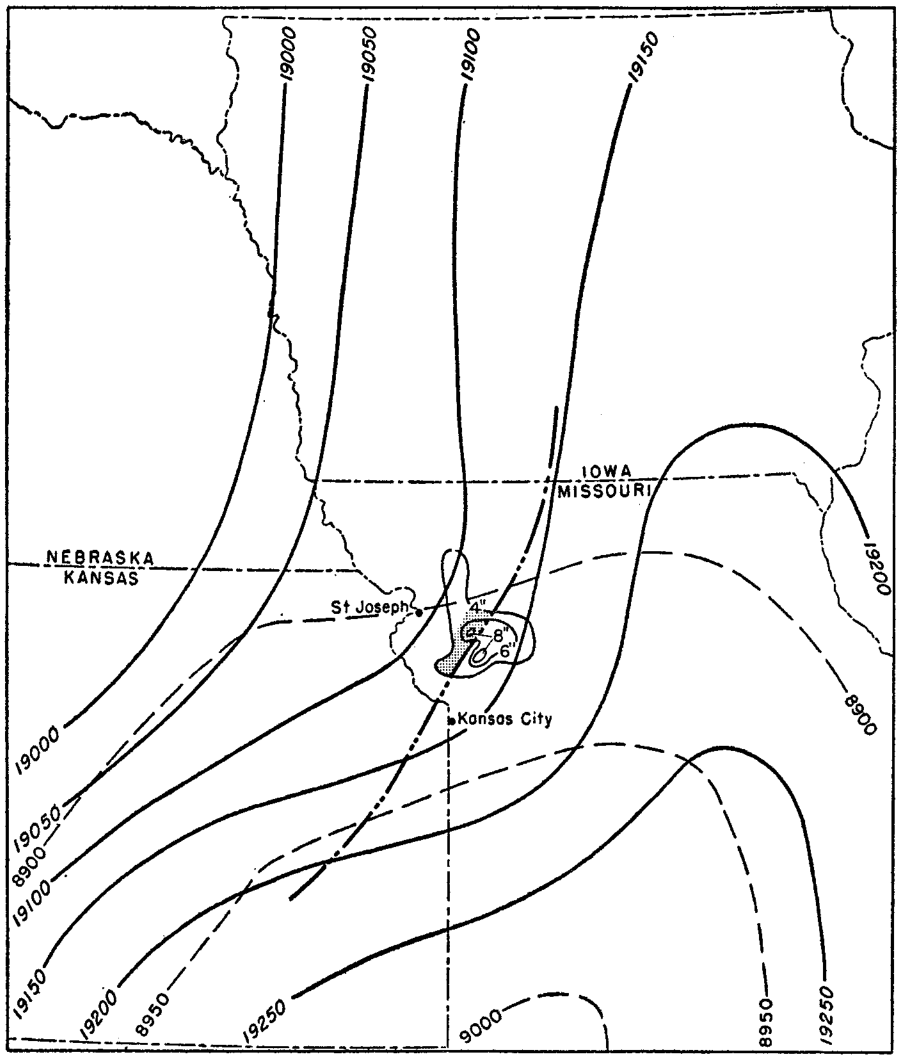

FIGURE 12.—500-mb. chart constructed as described in text for 1900 CST, June 22, 1947, the time of the Holt storm. Heavy lines are pressure contours (ft.); thin dashed lines are thickness contours, (ft.) of 700–500-mb. layer. Heavy dash-dot line represents leading edge of convection area at surface. Shaded portion of superimposed isohyetal pattern indicates rainfall rate of greater than 6 in./hr. at map time.

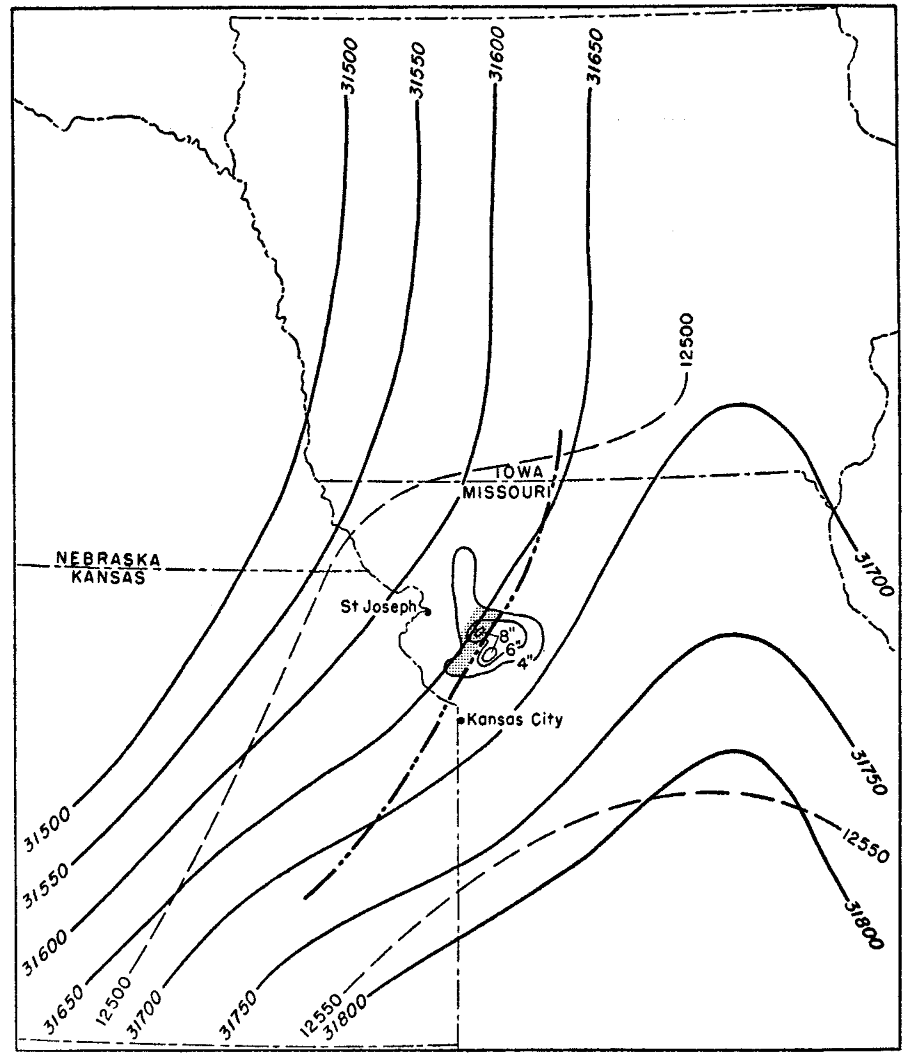

FIGURE 13.—300-mb. chart constructed as described in text for 1900 CST, June 22, 1947, the time of the Holt storm. Heavy lines are pressure contours (ft.); thin dashed lines are thickness contours (ft.) of 500–300-mb. layer. Heavy dash-dot line represents leading edge of convection area at surface. Shaded portion of superimposed isohyetal pattern indicates rainfall rate of greater than 6 in./hr. at map time.

to the convective area is evident, indicating an extremely favorable inflow of warm moist air in the critical low levels. The origin of the air in this easterly current was tropical as shown by the southward turning of the contour lines only a few miles upwind. The geostrophic wind was measured at 080°, 48 m. p. h. at the point of contact with the shower area.

The closed circulation at the surface and 850-mb. levels disappeared at the 700-mb. level (fig. 11). Cyclonically curved isobars brought in air from the southeast into the convective system.

The influence of the Low was fading at the 500-mb. level (fig. 12), while at 300 mb. (fig. 13) there appears to have been almost no influence of the surface system.

PROPOSED MECHANISM

The 1900 CST 850-mb. chart (fig. 10) must be thought of as a first approximation to the true conditions above the Holt storm center at that level. The temperature field in the convective area is, of course, the main unknown. Byers and Braham [3] suggest that the temperature at the 850-mb. level decreases somewhat in a thunderstorm rain area and that a very considerable cooling (about 5° C.) occurs in the 2,000–4,000 ft. layer. The 850-mb. cooling occurs about 3 miles to the rear of the surface wind shift line (in the average mature cell case). Since the cooling in the lower layers in the Holt storm was evaporational in nature, rather than frontal, it is probable that the horizontal temperature gradient at the 2,000–4,000 ft. level was only of the order of 2 miles to the rear of the surface outflow cooling. On the 850-mb. chart (fig. 10) the effect of the small Low was to turn the winds at that level from a previously southerly direction to a strong easterly. This could have the effect of forming a cross isotherm pattern of extraordinary strength and concentration. Areas of warm differential advection, especially if concentrated in the lowest layers, have been linked with strong vertical velocities [4]. A certain amount of conditional instability is favorable for continuation of the lifting process once the level of free convection is pierced (700 mb. in this case).

SUMMARY

This remarkably intense rainstorm was probably caused by a combination of several factors. Of great importance was the conditional instability in the tropical air mass. While the instability was a necessary condition for the storm and favored the development of warm sector convective systems, it was not sufficient to cause this explosive storm. A unique factor was the tightening of the pressure gradient north of an instability-line Low, causing an extraordinarily strong low-level flow of unstable air into the pre-existing convective system. The Holt storm occurred precisely at the point of injection into the convective system of the strongest winds in the layer between the surface and 850 mb.

It can be surmised that an area of strong differential advection could have been formed by the action of the combination of a pre-existent sharp temperature gradient and a sudden formation of a strong wind at right angles to this gradient by the uncommon pressure distribution.

ACKNOWLEDGMENT

The author desires to thank Dr. C. S. Gilman for his advice and encouragement during all phases of the storm study.

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CORRECTION

MONTHLY WEATHER REVIEW, vol. 82, No. 1, Jan. 1954, page 19: In the legends within figures 9a and 9b lines WW should be keyed as x x x and lines WWW as ● ● ● .